E0-E10-E15 Results from Phase 1 of EPAct Program

Sept 4, 2008

Preliminary information – not for release outside EPA

EPAct Program Overview

- EPA/DOE collaboration
- Objective: Establish effects of RVP,T50,T90, aromatic content and EtOH on exhaust emissions from Tier 2 vehicles
- Fuel matrix includes 29 fuels + 2 added by CRC: total of 31
- Test Program Design
  - Phase 1: RFS 2 Pilot at 75°F
    - 3 fuels (E0, E10 and E15) tested in 19 vehicles
    - Test results to be available for RFS 2 NPRM
  - Phase 2: RFS 2 Pilot at 50°F
    - Same as Phase 1, except temperature
  - Phase 3: Main Program
    - 25 fuels tested in 19 Tier 2 vehicles, E85 tested in 4 FFVs
- LA92 test cycle used throughout the program
- Species measured: Regulated emissions, CO_2, NO_2, VOCs, ethanol, carbonyl compounds
  - N_2O, NH_3 and HCN by FTIR
  - Some PM and SVOC speciation

Status of Testing

- Tests of E0, E10, E15 in the 19 Tier 2 vehicles have been completed
  - Preliminary statistical analysis is complete
- Test cell changeover for Phase 2 (50°F) underway
  - Expect start of testing by middle of this month
- Majority of testing and data processing issues have been resolved
  - Data transmission and QC by EPA
- Issues still requiring resolution include:
  - More accurate measurement of exhaust flow using Sensors EFM
  - Streamlining of fuel blending algorithms/software
  - Testing redesign may be consideration given:
    - Fuel blending difficulties
    - Initial findings in Phase 1 and 2
    - Augment with additional vehicles (NLEV), cycles, fuels, temps, evap

Phase 3 Fuel Blending Issue

- Need to make 25+ additional blends
  - (16) EPA blends including (8) E0 and (8) E10
  - (10) DOE blends including (3) E20, (6) E15 and (1) E85
  - (2) additional CRC fuels

- Supplier has approximately 25 “blendstocks”
  - Blendstocks may be single compounds or mixture
  - Very good at making staple fuels like Indolene
  - Not very good at tight parameter research fuel
  - Use “historical” knowledge-not exact formula

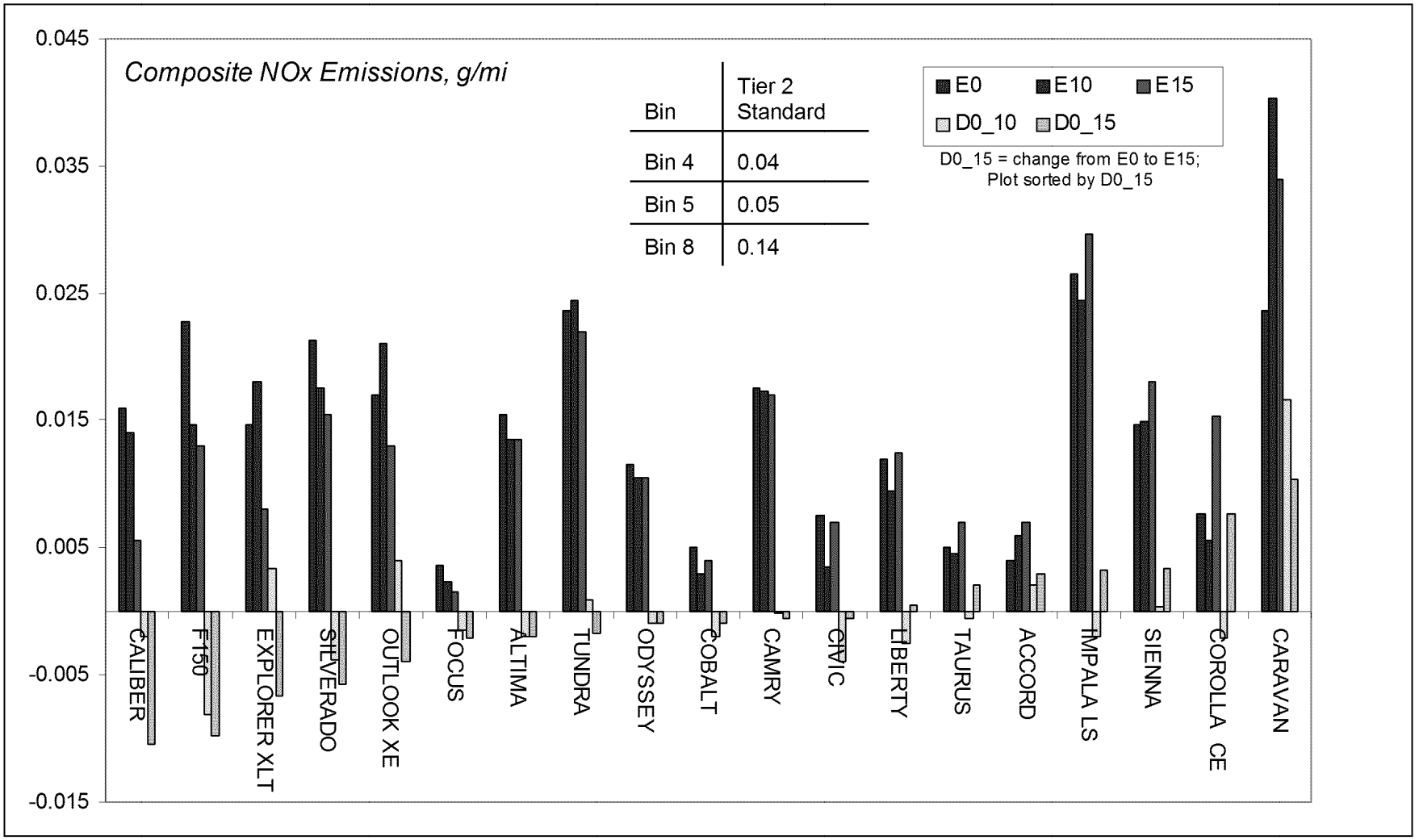
- EPA attempting to using “ASPEN” modeling software
  - Provides consistent blendstock portions approach
  - Some blendstock interactions are not fully understood
  - Currently not integrated prediction of desired (T#, arom.,RVP)
  - First attempts to use model output did not produce proper fuel
  - Falling behind on dates needed to have fuel formulas done
  - Delay of phase 3 or reduce ability to randomize fuels could result

Test Fuel Properties

PROPERTY	UNIT	METHOD	FUEL		
			E0	E10	E15
Ethanol Content	vol. %	D5599	<0.1	9.35	14.5
T50	ºF	D86	215	209	182
T90	ºF	D86	324	319	310
RVP	psi	D5191	9.17	9.05	8.91
Aromatics	vol. %	D1319	29.3	22.9	18.7
Olefins	vol. %	D1319	6.4	5.7	5.6
Benzene	vol. %	D3606	0.48	0.49	0.46
S	mg/kg	D5453	23	23	21
RON	-	D2699	93.4	93.7	93.9
MON	-	D2700	83.5	84.9	84.6
(R + M)/2	-	Calc.	88.5	89.3	89.2

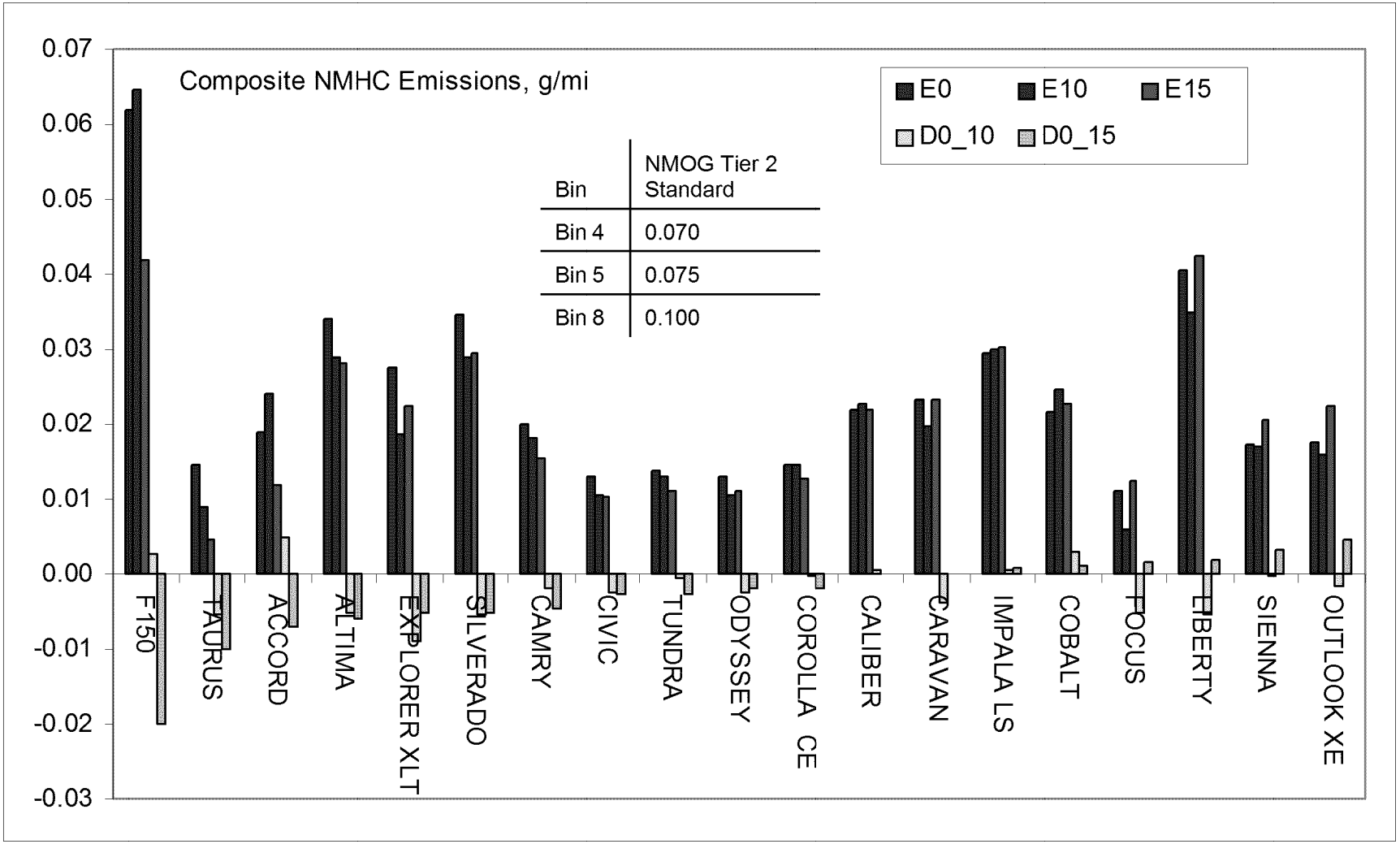
NOx Emissions

g/mi – means of measurements



NMHC Emissions

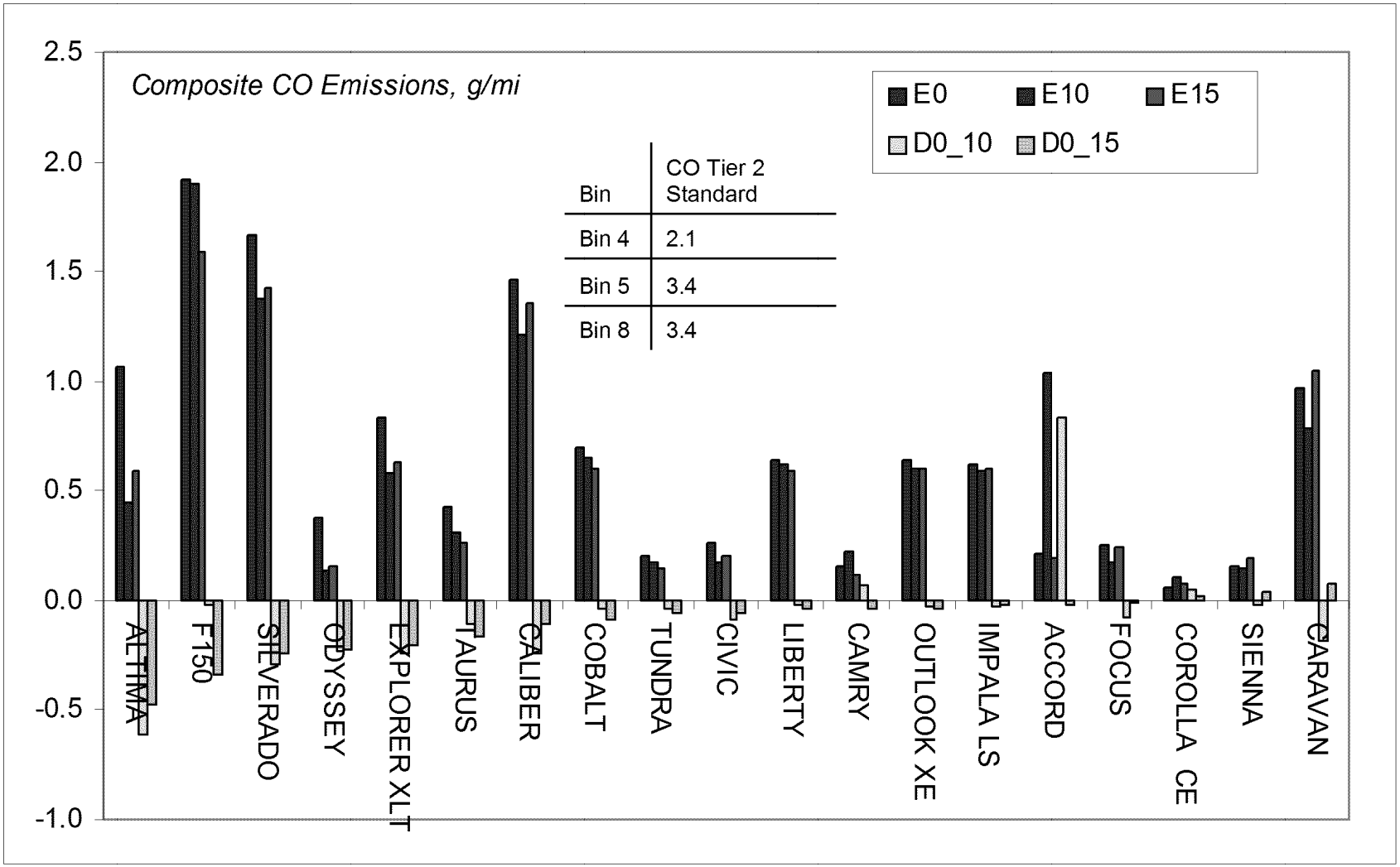
g/mi – means of measurements



Bin	NMOG Tier 2 Standard
Bin 4	0.070
Bin 5	0.075
Bin 8	0.100

CO Emissions

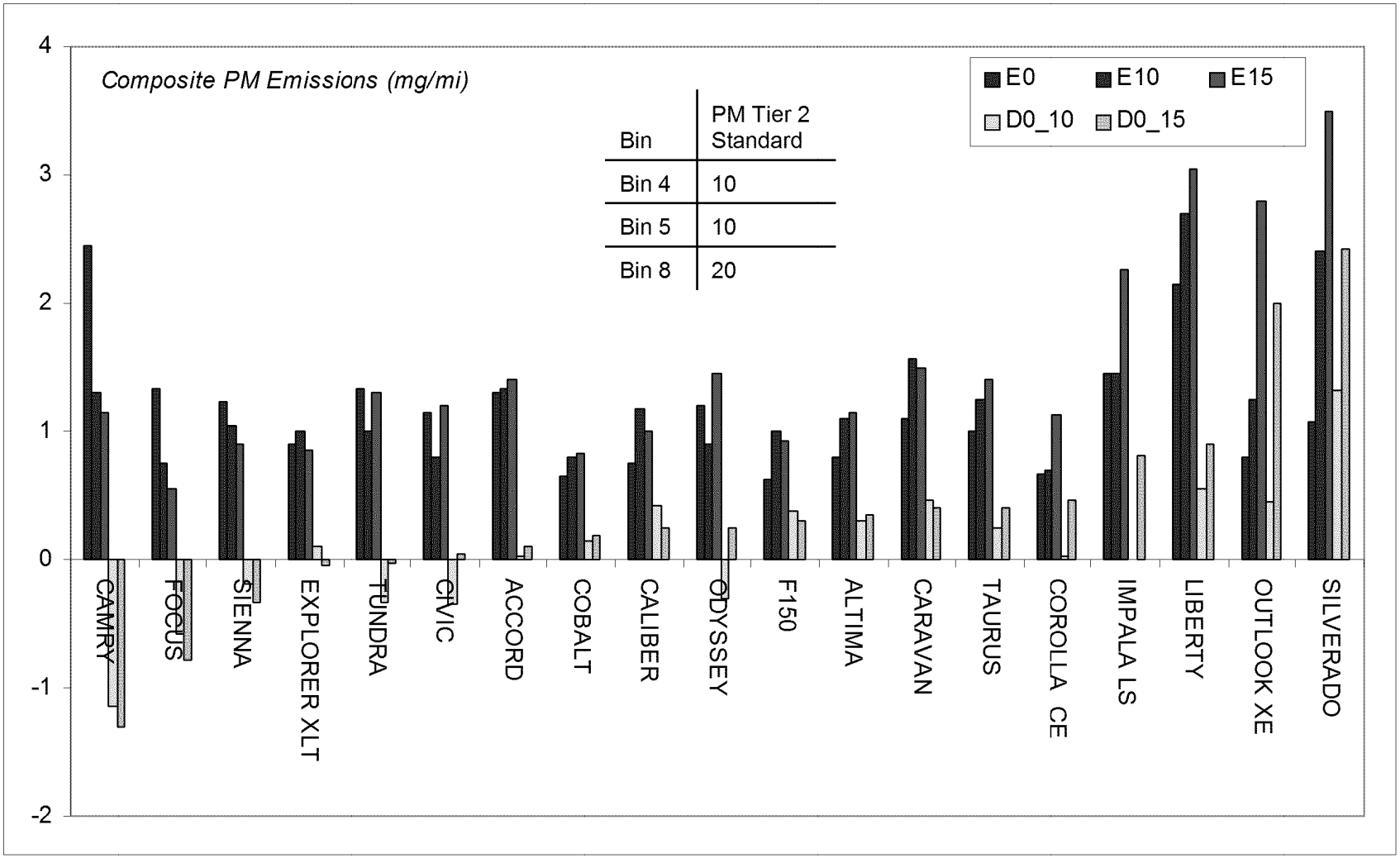
g/mi – means of measurements



Bin	CO Tier 2 Standard
Bin 4	2.1
Bin 5	3.4
Bin 8	3.4

PM Emissions

mg/mi – means of measurements



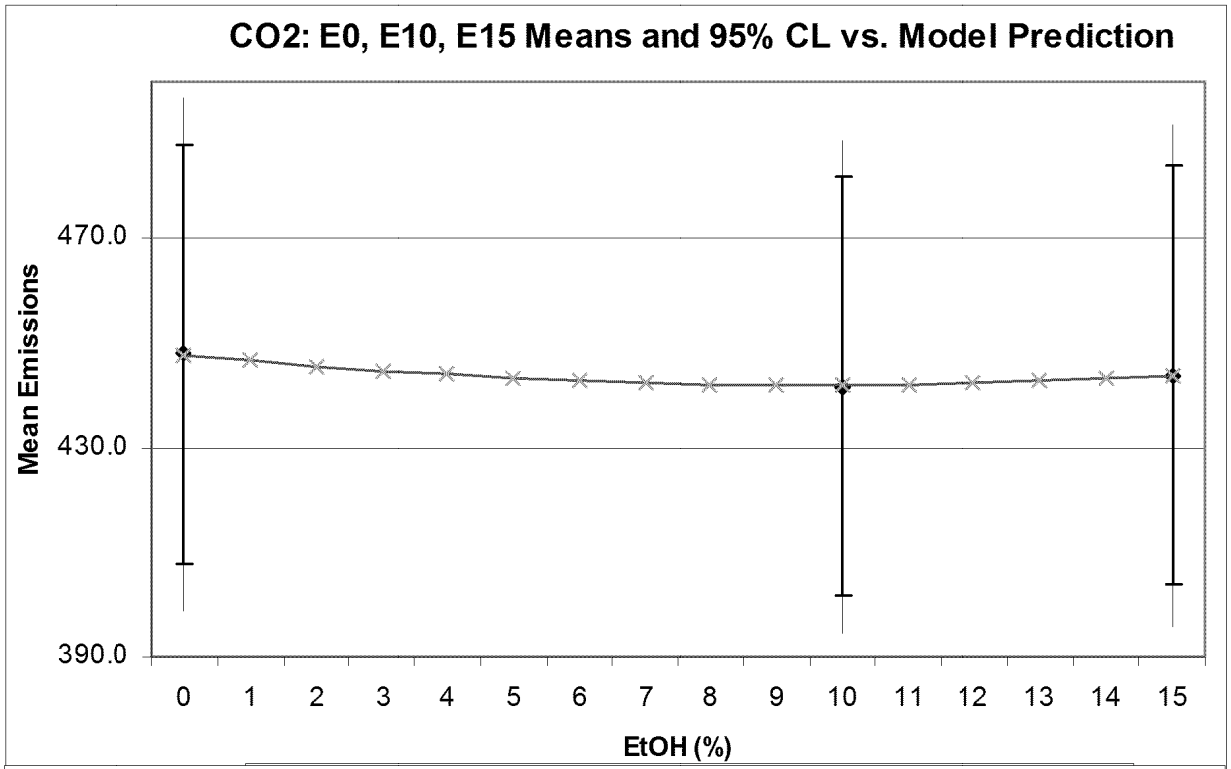
Emission Impacts - Model Outputs

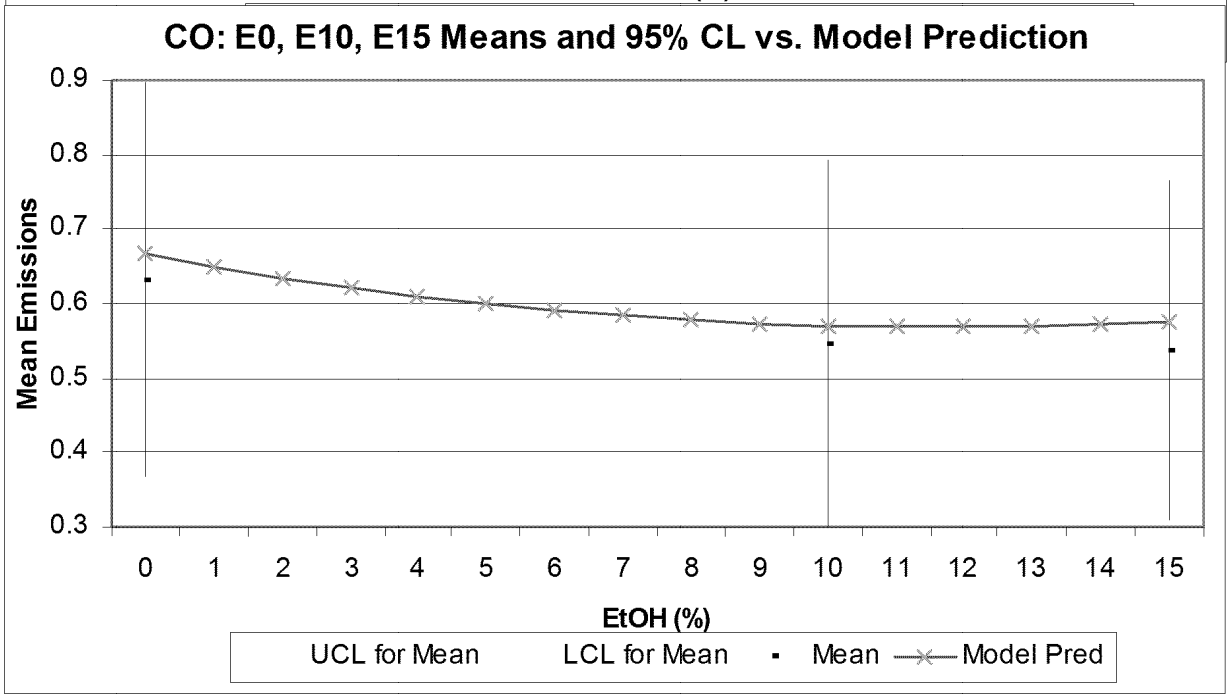
(Hoffman Categorical Analysis via Mixed Model, p≤0.05 or p≤0.10)

	E10 vs. E0 Relative Difference (%)				E15 vs. E0 Relative Difference (%)			
	Ph1	Ph2	Ph3	Comp	Ph1	Ph2	Ph3	Comp
NOx	-21.6				-18.3			
THC	-11.1		-27.8	-10.2				-9.8
CO	-14.6		-35.6	-13.8	-16.4		-30.5	-13.3
NMHC	-13.3		-38.1	-12.8			-35.4	-14.5
CO2	-1.5	-1.3	-1.0	-1.3	-0.8	-0.9	-0.6	-0.9
PM		-17.3	30.4		24.8		59.4	

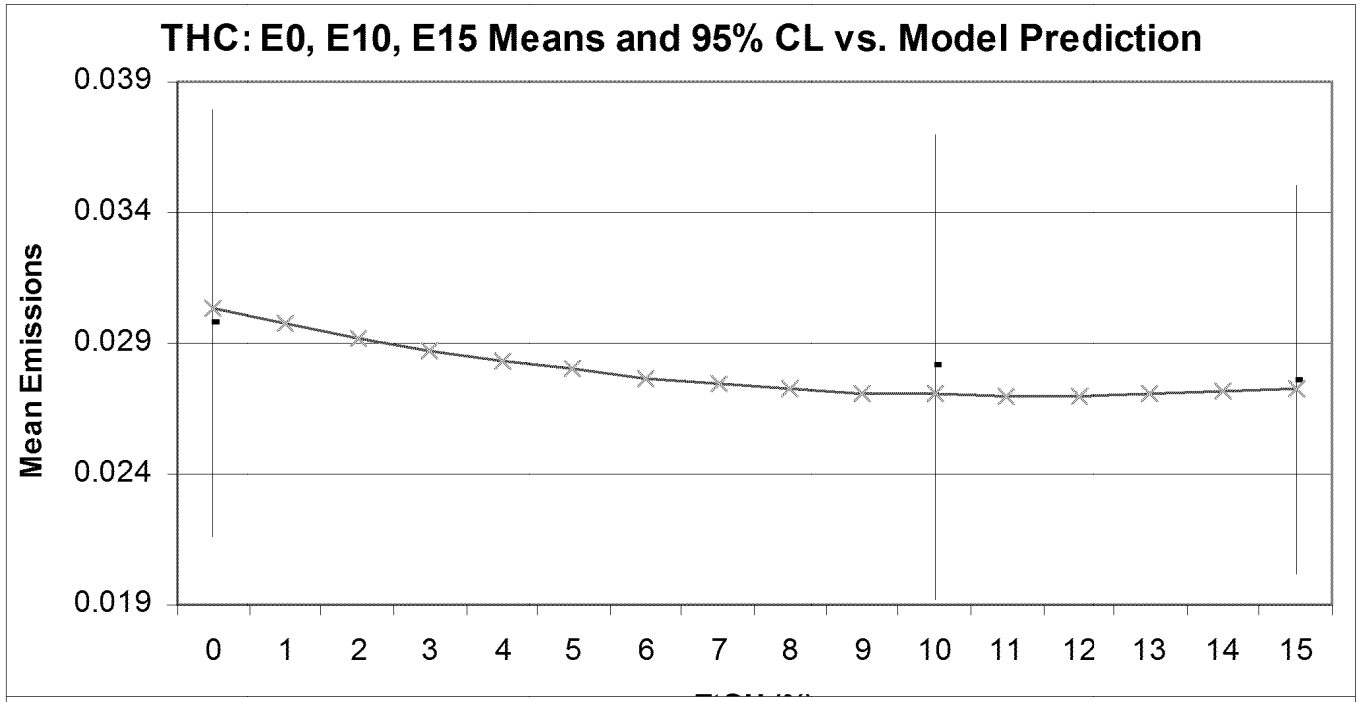
	E15 vs. E10 Relative Difference (%)			
	Ph1	Ph2	Ph3	Comp
NOx				
THC				
CO				
NMHC				
CO2	0.7			0.4
PM	21.9			18.5

- CO_2 and CO results
  - Both have significant drop from E0 to E10 then constant to E15
  - Means and continuous model shown for comparison

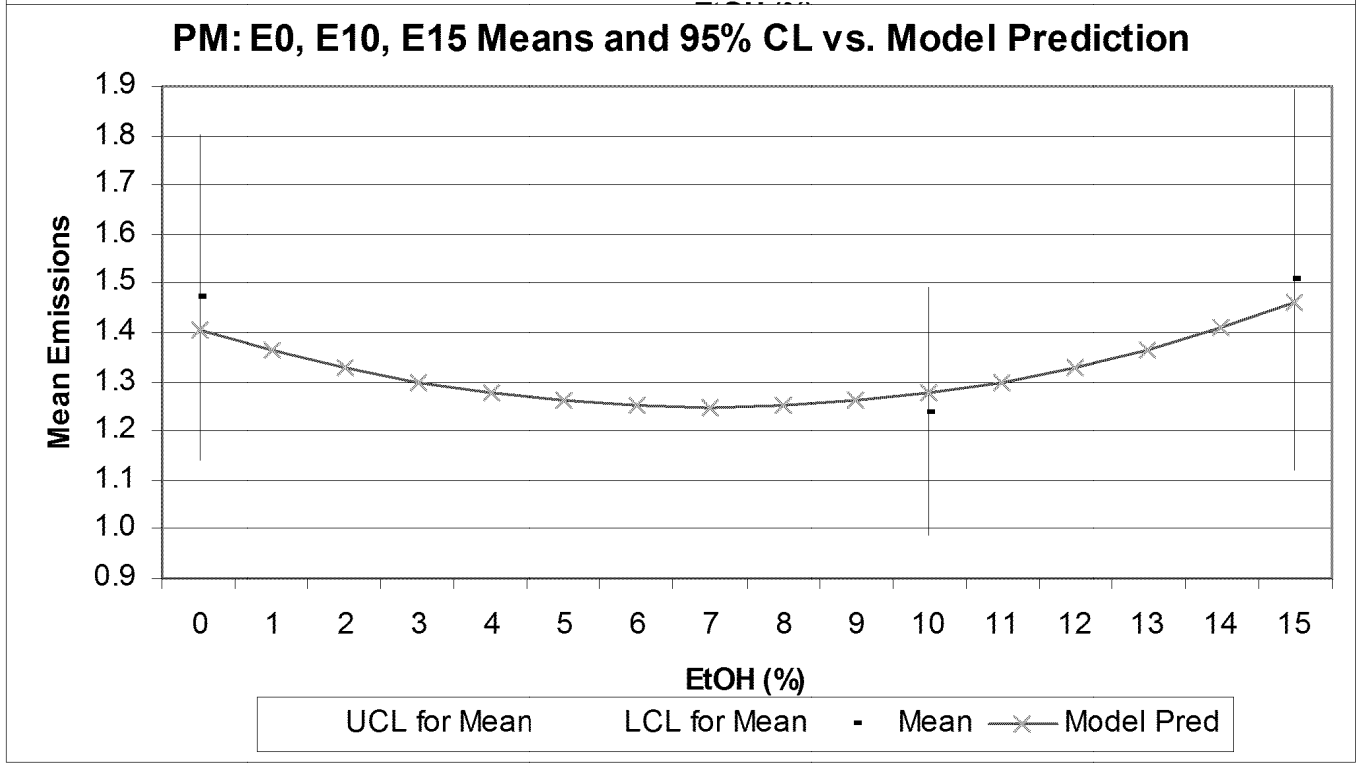




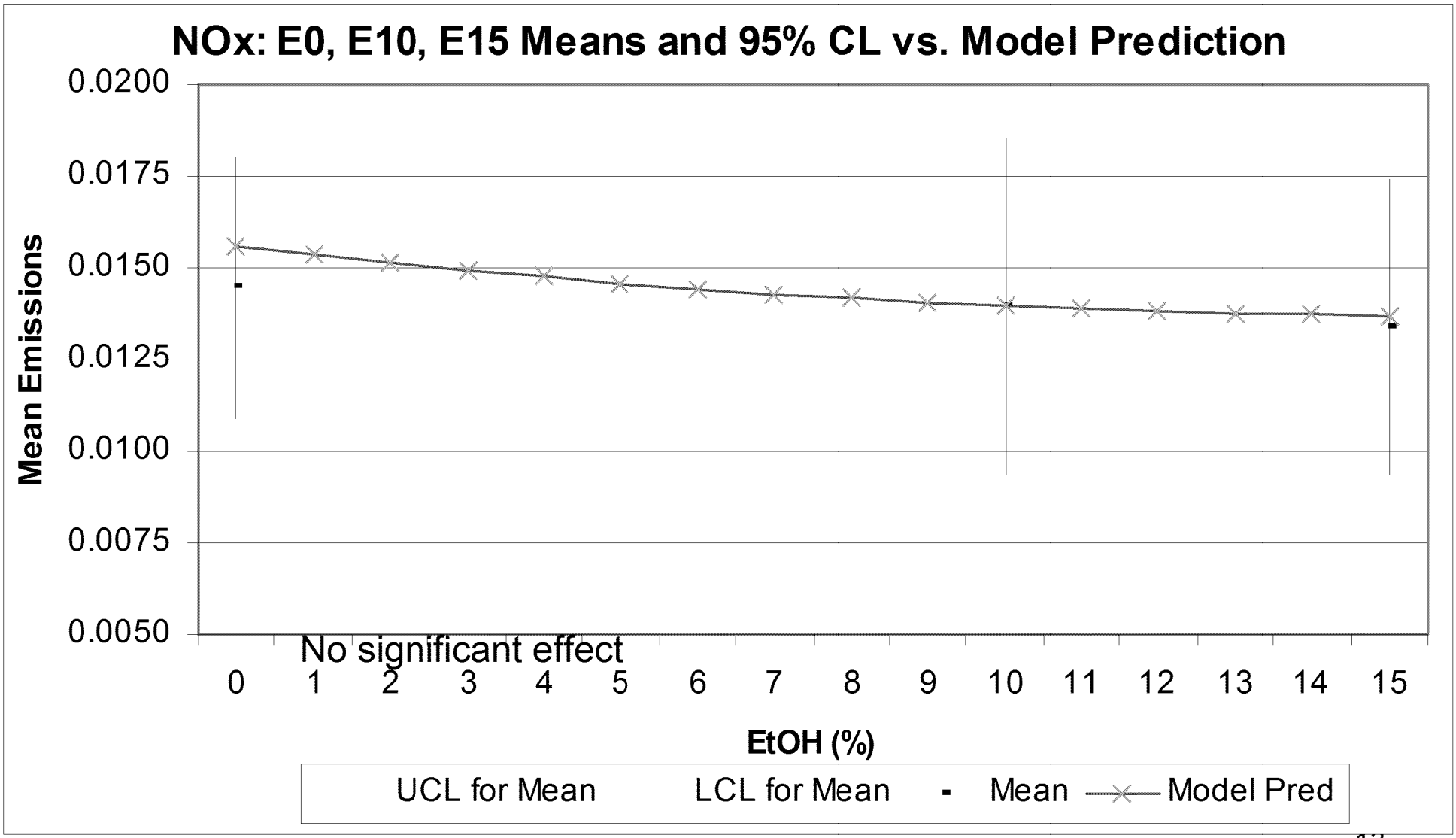
- THC
  - Significant drop from E0 to E10, but constant to E15



- PM
  - Significant drop from E0 to E10 then increasing to E15



NOx



Conclusions

- CO, HC, and PM all have significant decreases in emissions as ethanol levels increase from E0 to E10
- CO, HC and PM have insignificant changes from E10 to E15 (PM may even increase)
- NOx has significant decrease from E0 to E10 only for starts; over entire cycle composite, Tier 2 NOx seems to be insensitive to ethanol levels
  - This may be due to large variability (overwhelming effect) or insensitivity to fuel

Next steps

- Continue testing phase 2 (50°F)
- If we continue seeing no NOx effect, should we continue the program as is?
- Should we consider changing the program midstream (or even now)? Options?
  - Find/add some ethanol “sensitive” vehicles
  - Add some tests with fuels that have exactly same properties except for ethanol
  - Add FTP tests, which may magnify cold start impact
- If we continue as designed or expand, we will need to supplement with additional ’09 funds

Additional Slides

Revised EPAct Fuel Matrix

Phase 3
Base Program (EPA)
(Fuels 1-16) →

Phases 1 and 2
RFS 2 Subset (EPA/DOE)
(Fuels 17-19) →

Phase 3
Additional Fuels (DOE)
(Fuels 20-29) →

E85 (DOE) →

CRC Additional Fuels →

Fuel #	T50 °F	T90 °F	ETOH %	RVP psi	ARO %
1	150	300	10	10	15
2	240	340	0	10	15
3	220	300	10	7	15
4	220	340	10	10	15
5	240	300	0	7	40
6	190	340	10	7	15
7	190	300	0	7	15
8	220	300	0	10	15
9	190	340	0	10	40
10	220	340	10	7	40
11	190	300	10	10	40
12	150	340	10	10	40
13	220	340	0	7	40
14	190	340	0	7	15
15	190	300	0	10	40
16	220	300	10	7	40
17	215	325	0	9	30
18	202	325	10	9	25
19	195	325	15	9	23
20	160	300	20	7	15
21	160	300	20	7	40
22	160	300	20	10	15
23	160	340	20	7	15
24	160	340	20	10	15
25	160	340	20	10	40
26	150	340	15	10	40
27	190	340	15	7	15
28	190	300	15	7	40
29	TBD	TBD	85	TBD	TBD
30	150	325	10	10	40
31	160	325	20	10	15

Revised Fuels

Measured Species

- Bag (phase) level and composite emissions of THC, NMHC, NMOG, CO, CO_2, NOx, NO_2, ethanol and PM
- Bag (phase) level speciated volatile organic compounds (VOCs)
  - Over 200 compounds, incl. alcohols and carbonyls
- Continuous and integrated by bag (phase) emissions of the following species in raw exhaust:
  - THC, NMHC, CO, CO_2, NOx
  - N_2O, NH_3 and HCN by FTIR for a subset of tests
- Semi-volatile and high molecular weight VOC and PM measured in Phases 1 and 2 only

EPAct Vehicles vs. Tier 2 Emission Standards

EPAct Vehicle	Tier 2 Bin #	NMOG g/mile	CO g/mile	NOx g/mile	PM g/mile
Ford Focus, Ford Explorer	4	0.070	2.1	0.04	0.01
All other EPAct vehicles	5	0.075	3.4	0.05	0.01
Ford F150, Dodge Caravan	8	0.100	3.4	0.14	0.02

E10 Impacts on Emissions from Tier 2 Vehicles

CRC E-74b Program (7 Vehicles, Mixed Models, $p<0.05$)

Pollutant	Percent Change vs. E0			
	Weighted	Bag 1	Bag 2	Bag 3
NOx	-	-	-	-
NMHC	-12.9 ($0.1<p<0.05$)	-	-	-
CO	-22.4	-22.4	-	-
CO_2	-	-	-	-

EPAct Program Timeline

ORIGINAL EPAct PROGRAM TIMELINE DEFINED BY SWRI ON FEBRUARY 20, 2008

		JAN 2008				FEB 2008				MAR 2008					APR 2008				MAY 2008					JUN 2008					JUL 2008				AUG 2008				SEP 2008					OCT 2008				NOV 2008				DEC 2008				
		7	14	21	28	4	11	18	25	3	10	17	24	31	7	14	21	28	5	12	19	26	2	9	16	23	30	7	14	21	28	4	11	18	25	1	8	15	22	29	6	13	20	27	3	10	17	24	1	8	15	22	29
Phase 1[a]	6 weeks														1	2	3	4	5	6																																			
50F setup	3 weeks																				1	2	3																																
Phase 2[b]	9 weeks																							1	2	3	4	5	6	7	8	9																							
50F teardown	2 weeks																																1	2																				
NREL high emitters	3 weeks																																		1	2	3																
Phase 3[a]	26 weeks																																					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
NREL fuels[a]	17 weeks																																																				
draft final report	6 weeks																																																			
EPA/NREL review	4 weeks																																																			
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		5	12	19	26	2	9	16	23	2	9	16	23	30	6	13	20	27	4	11	18	25	1	8	15	22	29	6	13	20	27	3	10	17	24	31	7	14	21	28	5	12	19	26	2	9	16	23	30	7	14	21	28
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EPA/NREL review	4 weeks																																		1	2	3	4														
final report	4 weeks																																					1	2	3	4												

EPAct PROGRAM TIMELINE MODIFIED BY Rafal Sobotowski ON JUNE19, 2008

INCLUDES E20 TESTS FOR DOE and TWO CRC FUELS		JAN 2008				FEB 2008				MAR 2008					APR 2008				MAY 2008					JUN 2008					JUL 2008				AUG 2008				SEP 2008					OCT 2008				NOV 2008				DEC 2008				
		7	14	21	28	4	11	18	25	3	10	17	24	31	7	14	21	28	5	12	19	26	2	9	16	23	30	7	14	21	28	4	11	18	25	1	8	15	22	29	6	13	20	27	3	10	17	24	1	8	15	22	29
Phase 1[a]	14 weeks														1	2	3	4	5	6	7	8	9	10	11	12	13	14																													
50F setup	3 weeks																												1	2	3																							
Phase 2[b]	9 weeks																															1	2	3	4	5	6	7	8	9													
Blending of Phase 3 fuels	19 weeks																											1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20								
DOE E20 tests at 50F	2 weeks																																								1	2	3												
50F teardown	2 weeks																																											1	2								
DOE E20 tests at 75F	2 weeks																																												1	2							
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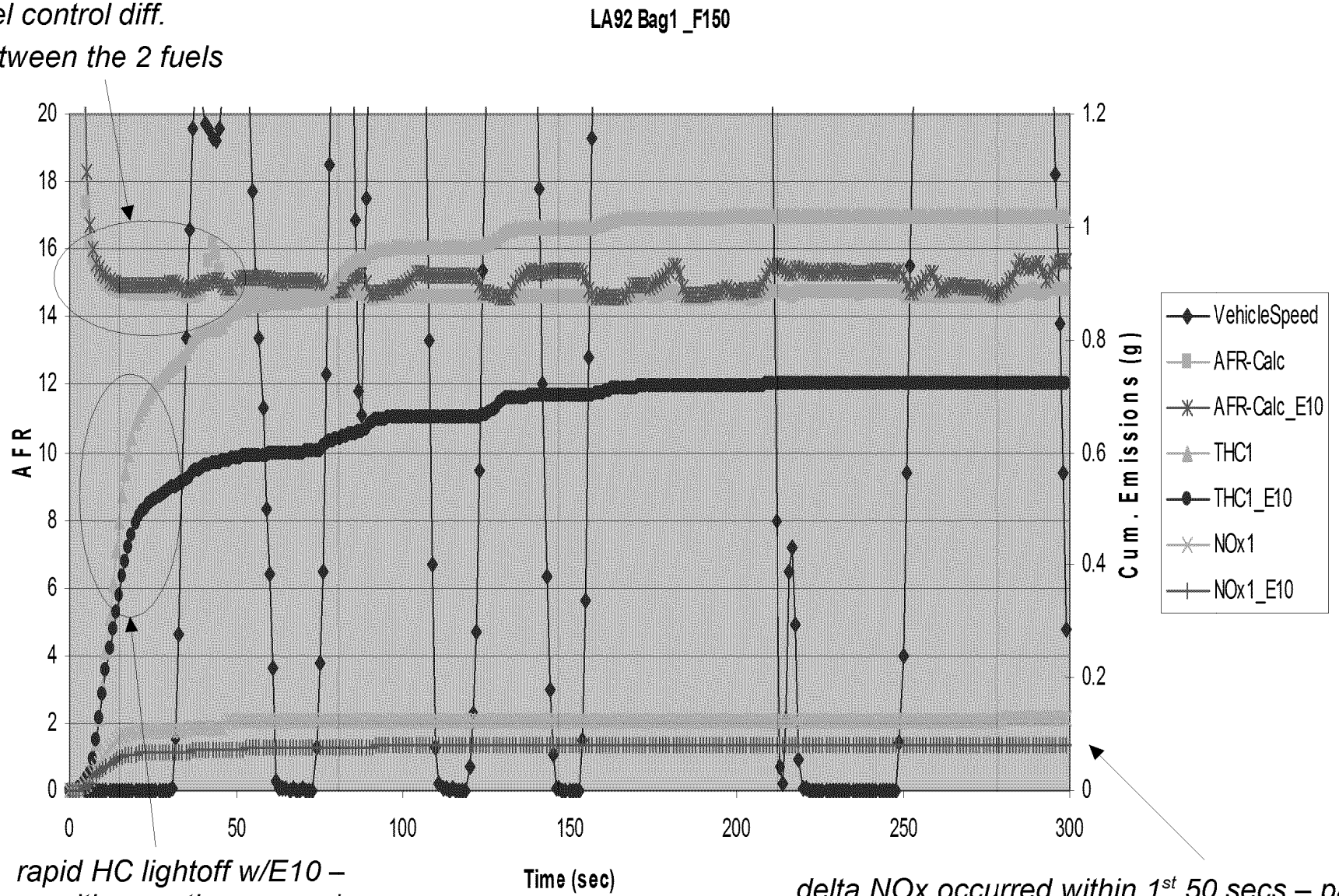
final report	4 weeks																																															1	2	3	4		

Initial Analysis of LA92 Bag1 Modal Data (EPAct)

Veh. w/largest NOx delta between E0 & E10

fuel control diff. between the 2 fuels

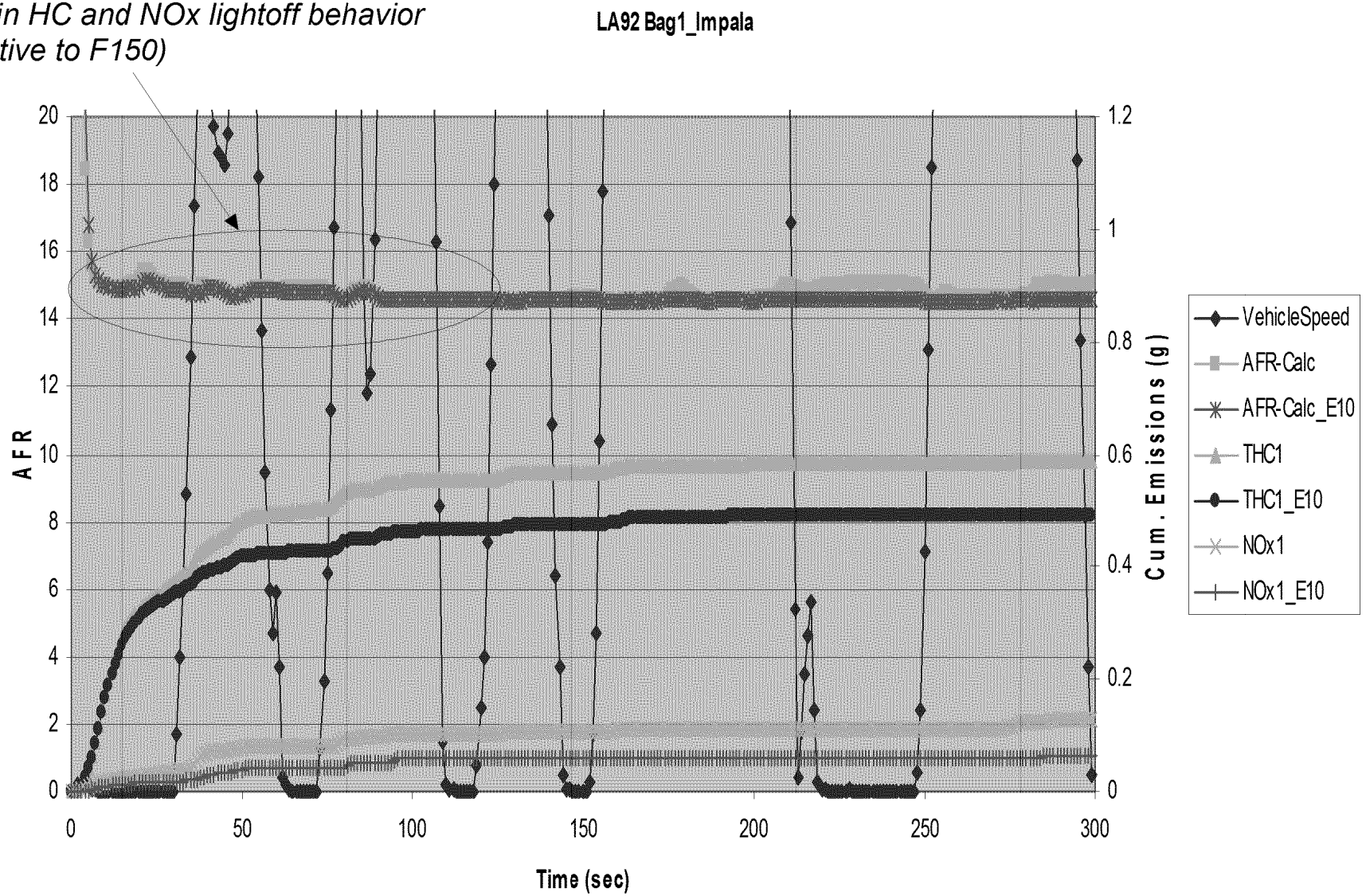


rapid HC lightoff w/E10 – resulting exotherm may improve NOx lightoff as well

delta NOx occurred within 1st 50 secs – parallel lines indicate equivalent NOx control for duration of bag

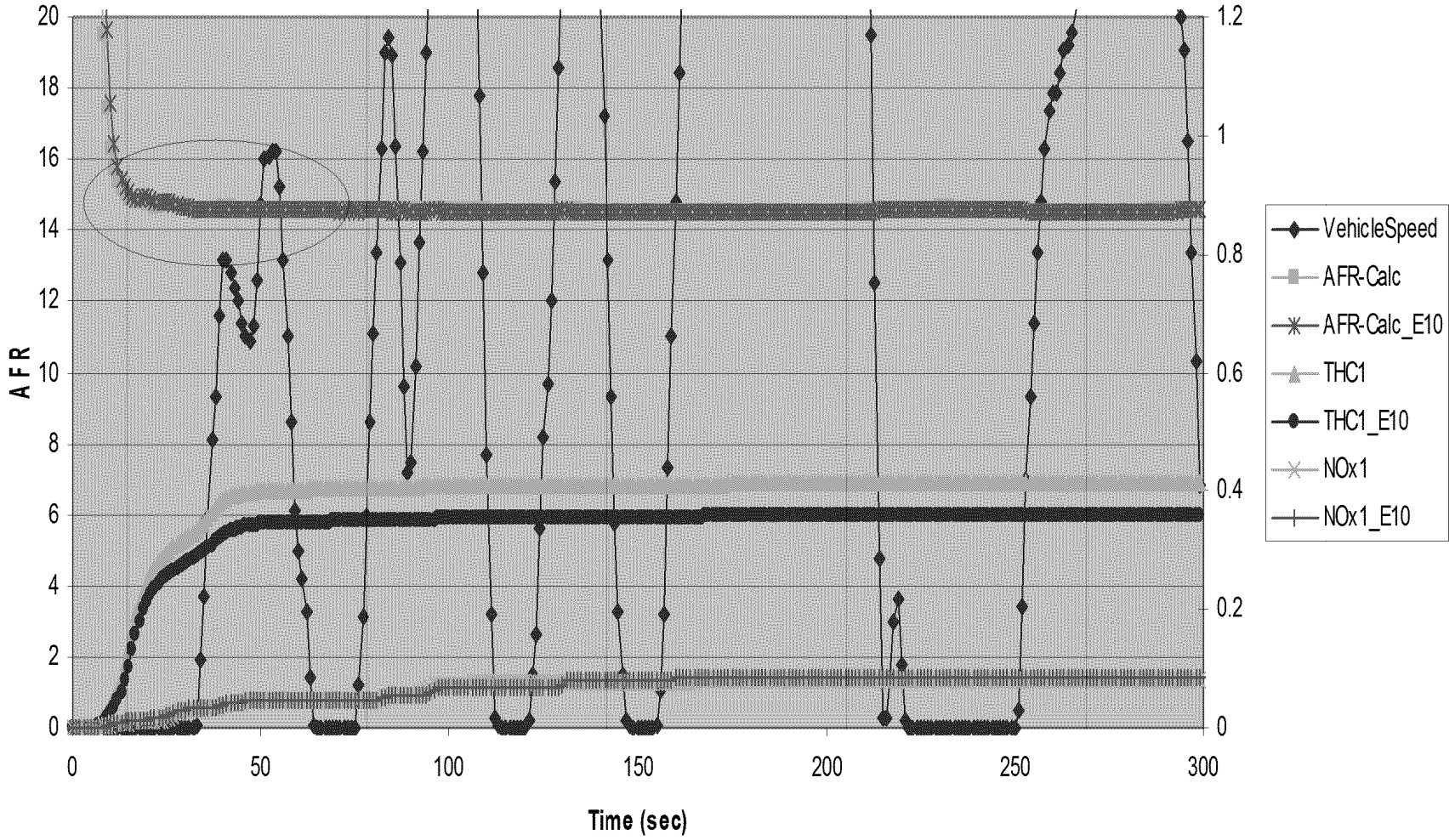
Veh. w/lesser NOx delta between E0 & E10

'tighter' fuel control – result is smaller diff. in HC and NOx lightoff behavior (relative to F150)



Veh. w/small NOx delta between E0 & E10

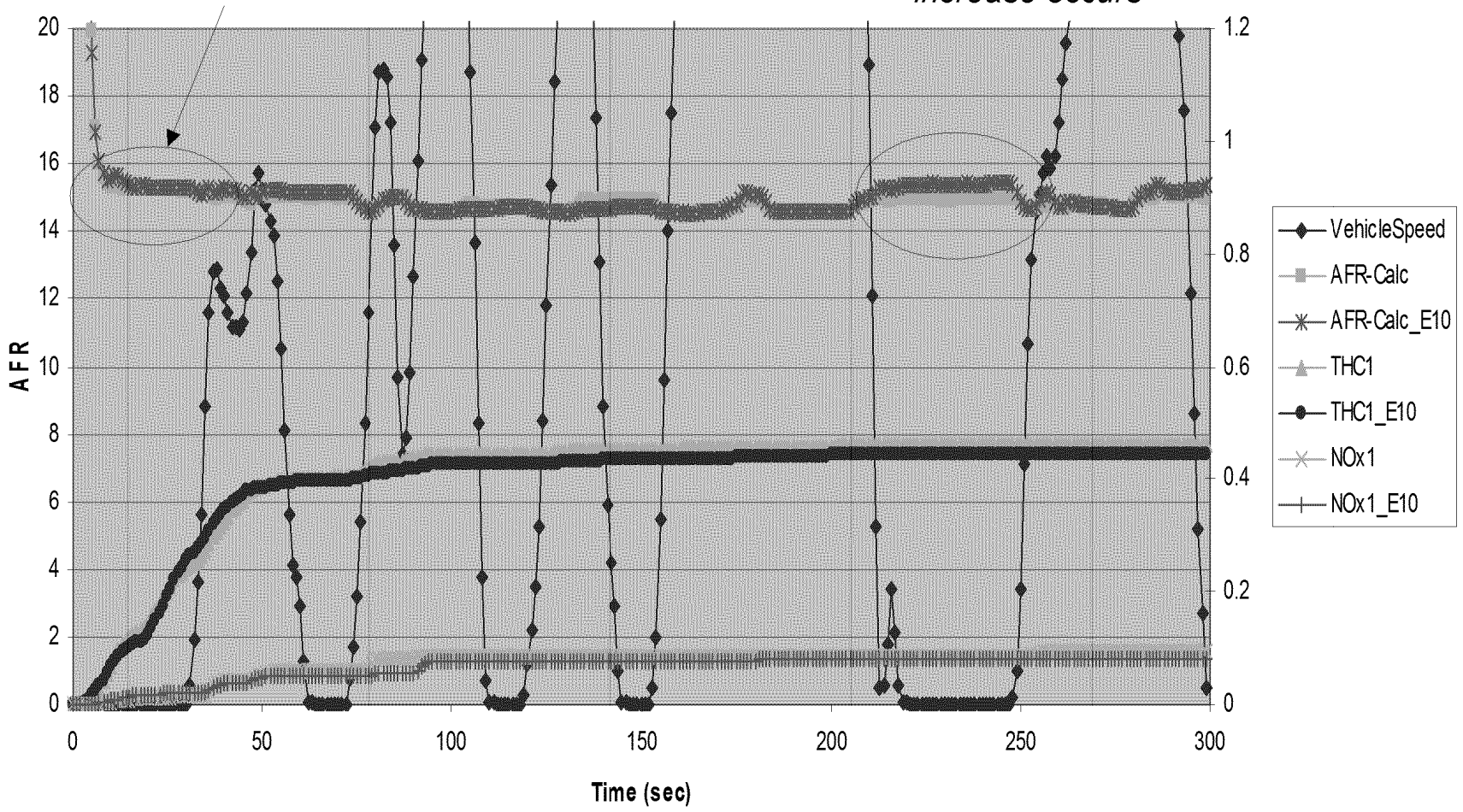
fuel control is near-identical –
result is smaller difference in HC
and NOx lightoff behavior



Veh. w/large positive NOx delta between E0 & E10

similar fuel control – result is similar HC and NOx lightoff behavior (and no HC or NOx delta in 1st 300 secs)

fuel control differences between E0 and E10 once engine is warm – need to look at other bags to find where NOx increase occurs



Initial Conclusions:

- How the fuel system reacts to each fuel affects how the catalyst "lights off"
  - A system w/lean bias on E10, will have quicker HC lightoff, which may also improve NOx lightoff
  - System with identical air-fuel ratio (AFR) traces on each fuel tend to have identical, or similar, lightoff behavior
- Fuel system control strategies are not uniform amongst the OEMs
  - Ford F150 … AFR traces separate at idle (even when engine is warm), and may/may not converge under load
  - Chevrolet Impala … little separation in AFR traces initially, but some separation when engine is warm
  - Toyota Corolla … as close to "line-for-line" as you can get
  - Dodge Caravan … little separation in AFR traces initially, but separation between fuels when warm is sometimes "rich" and sometimes "lean"
- Fuel effect on Bag1 NOx emissions is manufacturer-dependent – those with "tight" fuel control (regardless of ethanol content) show a small NOx effect, while those with "separation" show a larger NOx effect